



DEPARTMENT OF MECHANICAL ENGINEERING

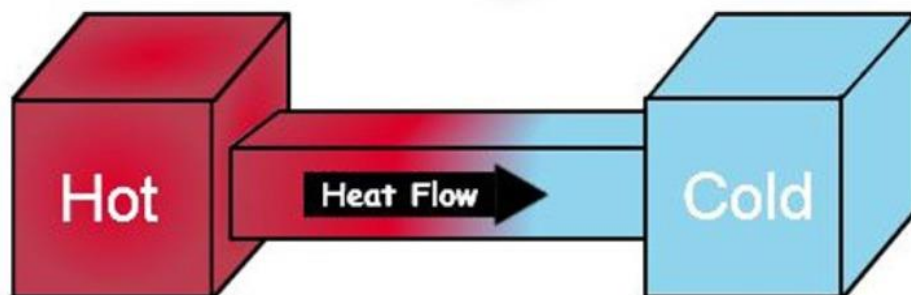


IMPORTANT

SHORT QUESTIONS WITH ANSWER

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Thermodynamics





Q. 1.What is an air-standard efficiency ?

Ans-

- To compare the effects of different cycles, it is important that the effect of the calorific value of the fuel is altogether eliminated and this can be achieved by considering air (which is assumed to behave as a perfect gas) as the working substance in the engine cylinder. The efficiency of engine using air as the working medium is known as an “Air standard efficiency”. This efficiency is often called ideal efficiency.
- The actual efficiency of a cycle is always less than the air-standard efficiency of that cycle under ideal conditions.
- This is taken into account by introducing a new term “Relative efficiency” which is defined as :

$$\eta_{\text{relative}} = \text{Actual thermal efficiency} / \text{Air standard efficiency}$$

Q. 2.The efficiency of an Otto cycle is 60% and $\gamma = 1.5$. What is the compression ratio ?

Ans. Efficiency of Otto cycle, $\eta = 60\%$ Ratio of specific heats, $\gamma = 1.5$ Compression ratio, $r = ?$ Efficiency of Otto cycle is given by,

$$\eta_{\text{Otto}} = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$0.6 = 1 - \frac{1}{(r)^{1.5-1}}$$

$$\Rightarrow \frac{1}{(r)^{0.5}} = 0.4 \Rightarrow r = 6.25$$

Hence, compression ratio=6.25.



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Q.3. Draw the p-v and T-s diagram of Otto cycle?

Ans-

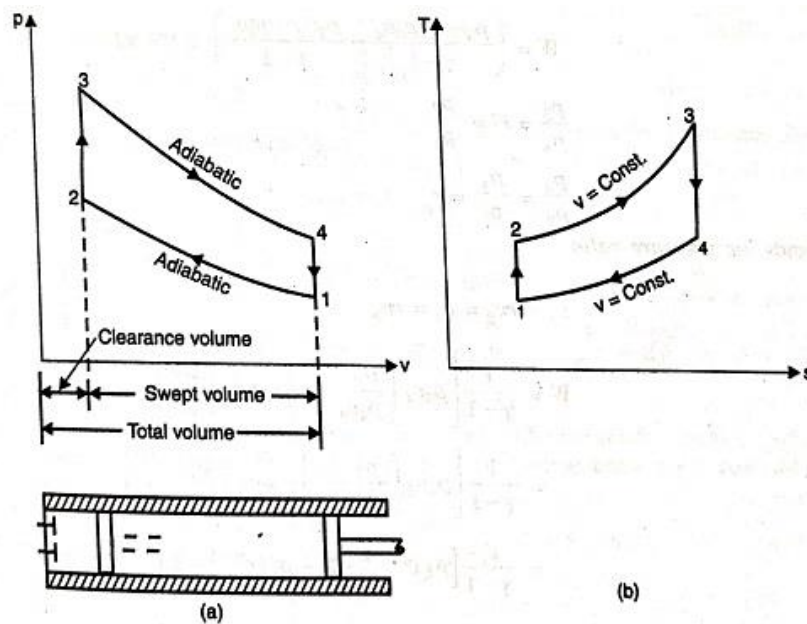


Fig.

Q.4. Draw the p-v and T-s diagram of Diesel cycle?

Ans-

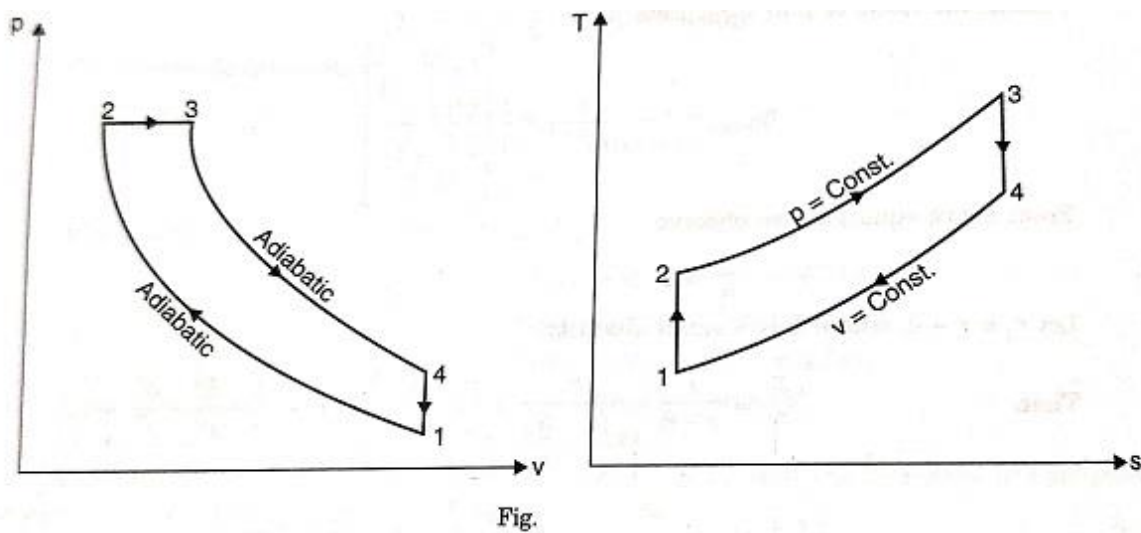
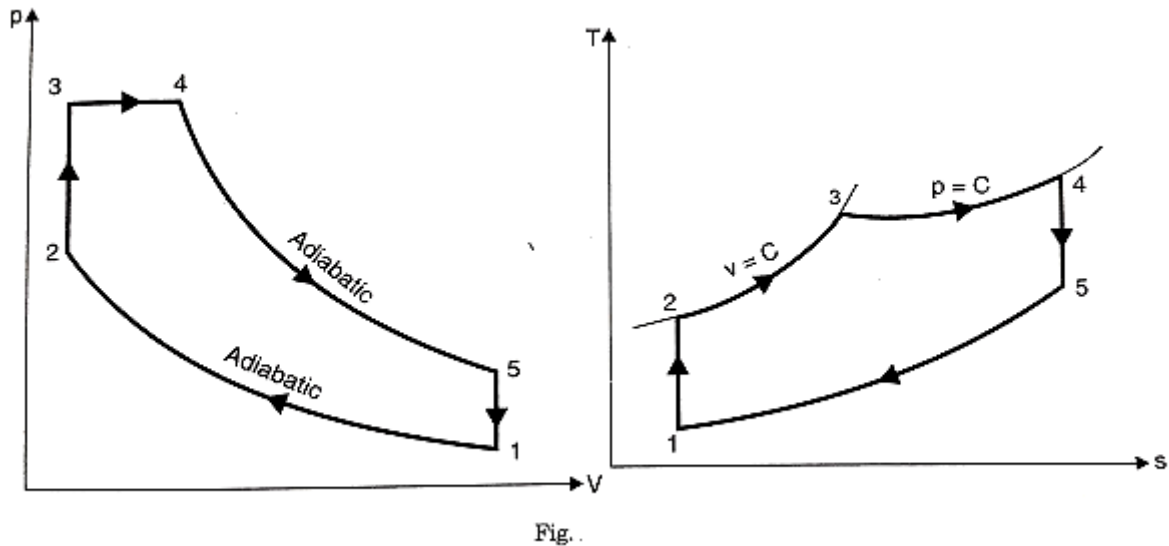


Fig.



Q.5. Draw the p-v and T-s diagram of Dual cycle?

Ans-



Q.6. What is cut-off ratio?

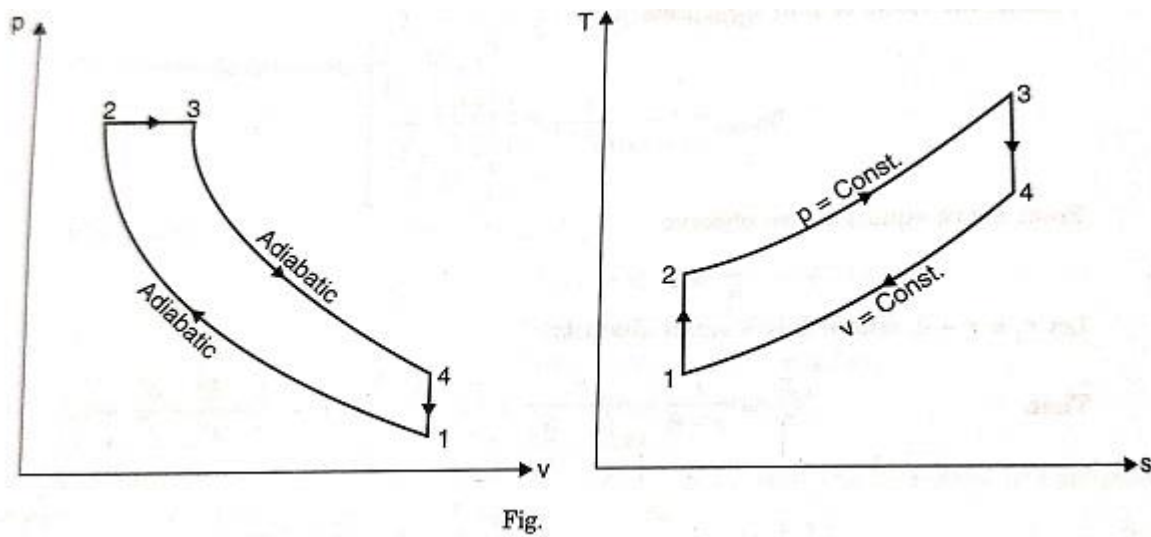
Ans-

CONSTANT PRESSURE OR DIESEL CYCLE

- This cycle was introduced by Dr. R. Diesel in 1897. It differs from Otto cycle in that heat is supplied at constant pressure instead of at constant volume. Fig. shows the p-v and T-s diagrams of this cycle respectively.
- This cycle comprises of the following operations :
 - (i) 1-2.....Adiabatic compression.
 - (ii) 2-3.....Addition of heat at constant pressure.
 - (iii) 3-4.....Adiabatic expansion.
 - (iv) 4-1.....Rejection of heat at constant volume.



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- Fig.
- Point 1 represents that the cylinder is full of air. Let p_1 , V_1 and T_1 be the corresponding pressure, volume and absolute temperature. The piston then compresses the air adiabatically (i.e., $pV^\gamma = \text{constant}$) till the values become p_2 , V_2 and T_2 respectively (at the end of the stroke) at point 2. Heat is then added from a hot body at a constant pressure.
 - During this addition of heat let volume increases from V_2 to V_3 and temperature T_2 to T_3 , corresponding to point 3. This point (3) is called the point of cut-off, where fuel supply is cut off.
 - The air then expands adiabatically to the conditions p_4 , V_4 and T_4 respectively corresponding to point 4. Finally, the air rejects the heat to the cold body at constant volume till the point 1 where it returns to its original state.
 - cut-off ratio, $\rho = \frac{V_3}{V_2}$ i.e., $\frac{\text{volume at cutoff}}{\text{clearance volume}}$

Q. 7. A diesel engine has a compression ratio of 15 and heat addition at constant pressure takes place at 6% of stroke. Find the air standard efficiency of the engine. Take γ for air as 1.4.

Solution.

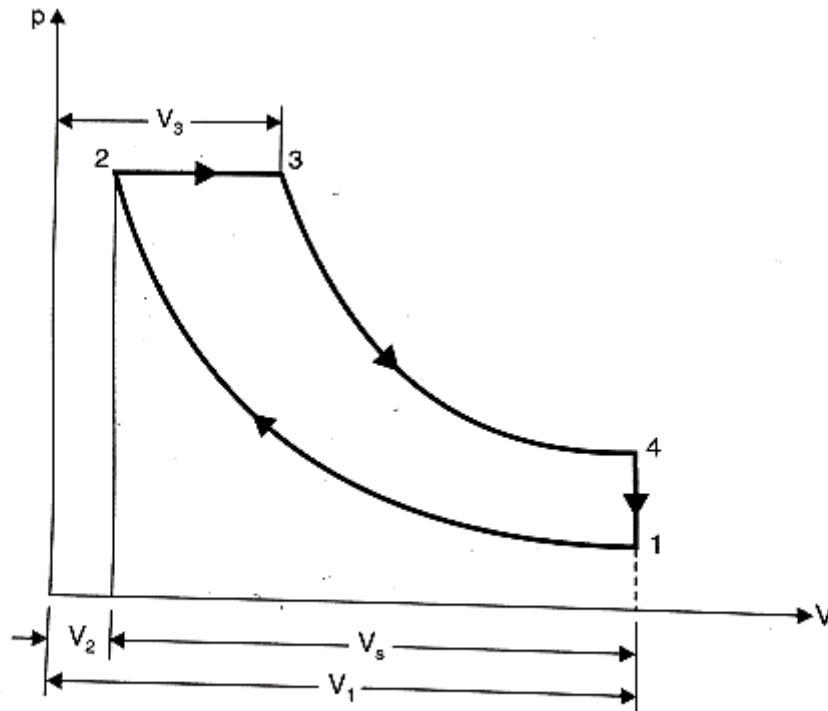


Fig.

- Compression ratio, $r = \frac{V_1}{V_2} = 15$
- γ for air = 1.4
- Air standard efficiency of diesel cycle is given by
- $$\eta_{diesel} = 1 - \frac{1}{\gamma(r)^{\gamma-1}} \left[\frac{\rho^\gamma - 1}{\rho - 1} \right]$$
- where $\rho = \text{cut-off ratio} = \frac{V_3}{V_2}$
- But $V_3 - V_2 = \frac{6}{100} V_s$ (Vs = stroke volume)
- $= 0.06 (V_1 - V_2) = 0.06 (15 V_2 - V_2)$
- $= 0.84 V_2$ or $V_3 = 1.84 V_2$



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$$\rho = \frac{v_3}{v_2} = \frac{1.84v_2}{v_2} = 1.84$$

➤ So we get,

$$\eta_{diesel} = 1 - \frac{1}{1.4(15)^{1.4-1}} \left[\frac{(1.84)^{1.4} - 1}{1.84 - 1} \right] = 0.612 = 61.2\%$$

Q.8. What is work ratio?

Ans-Work ratio is defined as the ratio of net work output to the work done by the turbine.

$$\therefore \text{workratio} = \frac{W_T - W_C}{W_T} \quad [\text{Where, } W_T = \text{Work obtained from this turbine, and } W_C = \text{work supplied to compressor.}]$$

Q. 9. Draw the p-v and T-s diagram of Brayton cycle?

Ans-

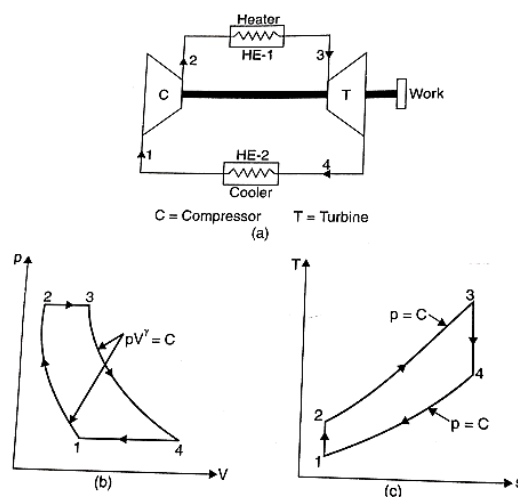


Fig. . Brayton cycle : (a) Basic components of a gas turbine power plant
(b) p-V diagram (c) T-s diagram.



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Q.10. Define relative C.O.P.

Ans- The performance of a refrigeration system is expressed by a term known as the “co-efficient of performance”, which is defined as the ratio of heat absorbed by the refrigerant while passing through the evaporator to the work input required to compress the refrigerant in the compressor ; in short it is the ratio between heat extracted and work done.

If, R_n = Net refrigerating effect, W = Work during the same interval of time,

Then,
$$C.O.P. = \frac{R_n}{W}$$

And
$$Relative C.O.P. = \frac{Actual C.O.P.}{Theoretical C.O.P.}$$

where, Actual C.O.P. = Ratio of R_n and W actually measured during a test and,

Theoretical C.O.P. = Ratio of theoretical values of R_n and W obtained by applying laws of thermodynamics to the refrigeration cycle.

Q.11. what is a tonne of refrigeration?

Ans-

- The rating of a refrigeration machine is obtained by refrigerating effect or amount of heat extracted in a given time from a body.
- The rating of the refrigeration machine is given by a unit of refrigeration known as “standard commercial tonne of refrigeration” which is defined as the refrigerating effect produced by the melting of 1 tonne of ice from and at 0°C in 24 hours.
- Since the latent heat of fusion of ice is 336 kJ/kg, the refrigerating effect of 336×1000 kJ in 24 hours is rated as one tonne, i.e.,

$$1 \text{ tonne of refrigeration (TR)} = \frac{336 \times 1000}{24} = 14000 \text{ KJ / h}$$

Note : Ton of refrigeration (TR). A ton of refrigeration is basically an American unit of refrigerating effect (R.E.). It originated from the rate at which heat is required to be removed to freeze one ton of water from and at 0°C . Using American units this is equal to removal of 200 BTU of heat per minute, and MKS unit it is adopted as 50 kcal/min or 3000 kcal/hour. In S.I. units its conversion is rounded off to 3.5 kJ/s (kW) or 210 kJ/min.

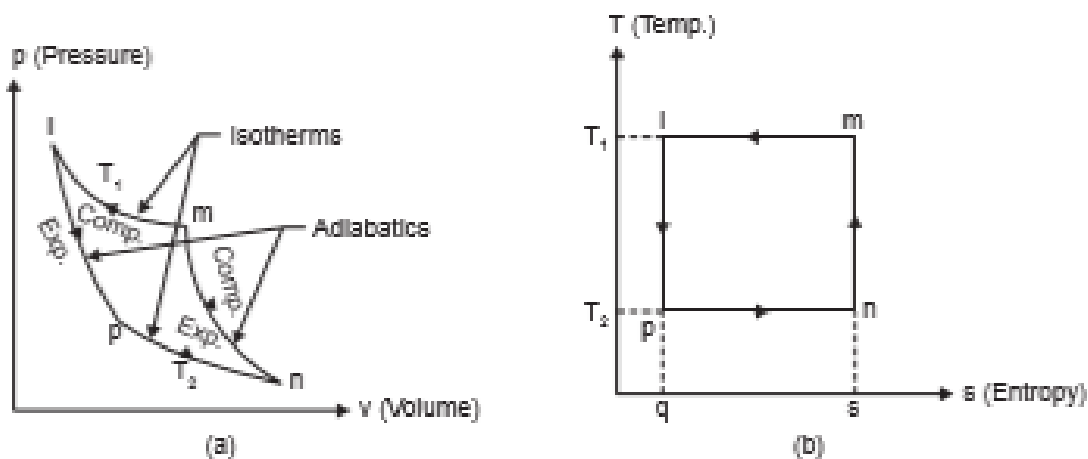


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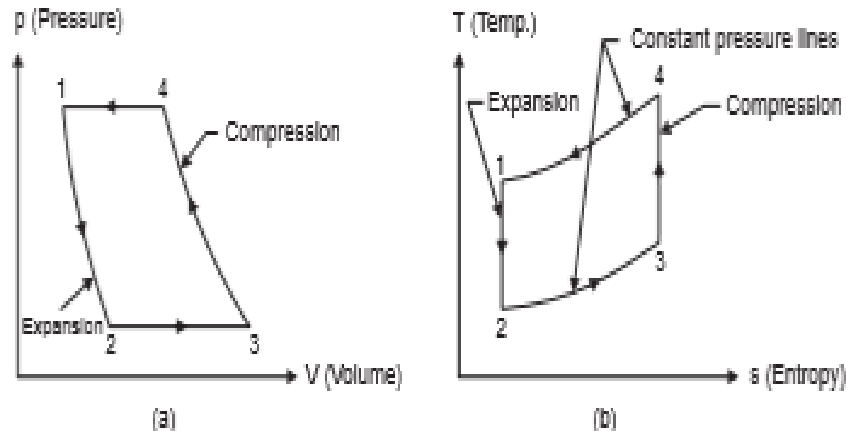
Q.12. Draw the p-v and T-s diagram of reversed Carnot cycle?

Ans-



Q.13. Draw the p-v and T-s diagram of reversed Brayton cycle?

Ans-



Q.14. What are the Merits and Demerits of Air refrigeration System?

Ans-

Merits

1. Since air is non-flammable, therefore there is no risk of fire.
2. It is cheaper as air is easily available as compared to the other refrigerants.
3. As compared to the other refrigeration systems the weight of air refrigeration system per tonne of refrigeration is quite low, because of this reason this system is employed in aircrafts.



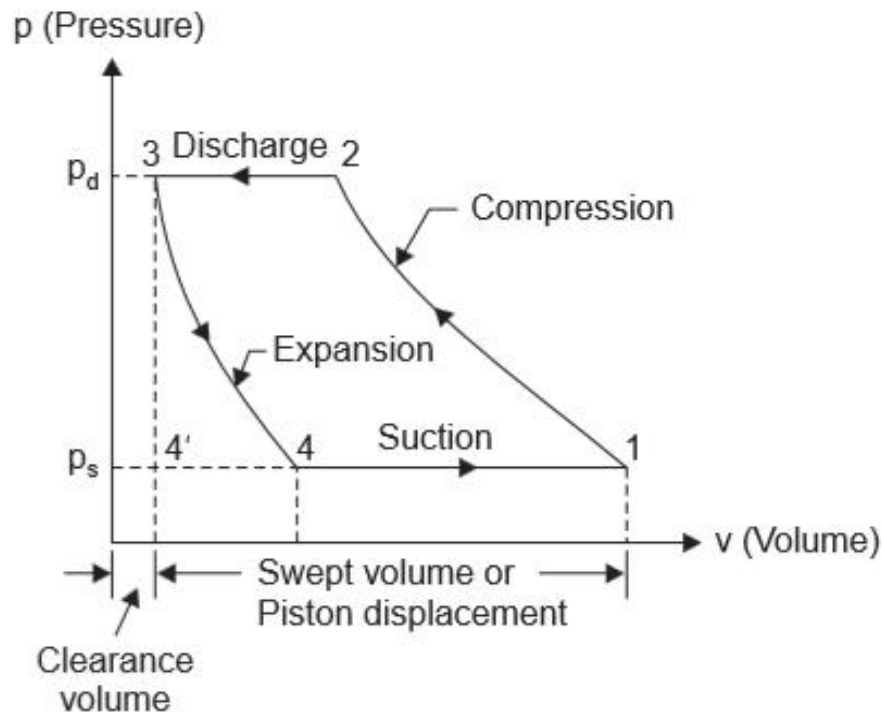
Demerits

1. The C.O.P. of this system is very low in comparison to other systems.
2. The weight of air required to be circulated is more compared with refrigerants used in other systems. This is due to the fact that heat is carried by air in the form of sensible heat.

Q.15. what is Clearance volumetric efficiency?

Ans-

- 'Clearance volume' is the volume of space between the end of the cylinder and the piston when the latter is in dead centre position. The clearance volume is expressed as a percentage of piston displacement. In Fig. the piston displacement is shown as 4'-1.



- During the suction stroke 4'-1, the vapour filled in clearance space at a discharge pressure p_d expands along 3-4 and the suction valve opens only when pressure has dropped to suction pressure p_s , therefore actual volume sucked will be $(v_1 - v_4)$ while the swept volume is $(v_1 - v_4')$. The ratio of actual volume of vapour sucked to the piston displacement is defined as clearance volumetric efficiency.

Thus,

$$\text{Clearance volumetric efficiency, } \eta_{cv} = \frac{v_1 - v_4}{v_1 - v_4'} = \frac{v_1 - v_4}{v_1 - v_3} (\because v_4' = v_3)$$



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Q.16. Compare between Vapour Compression and Vapour Absorption Systems.

S. No	Particulars	Vapour compression system	Vapour absorption system
1	Type of energy supplied	Mechanical—a high grade	Mainly heat—a low grade energy
2	Energy supply	Low	High
3	Wear and tear	More	Less
4	Performance at part load	Poor	System not affected by variations of loads
5	Suitability	Used where high grade mechanical energy is available	Can also be used at remote places as it can work even with a simple kerosene lamp (of course in small capacities)
6	Charging of refrigerant	simple	Difficult
7	Leakage of refrigerant	More chances	No chance as there is no compressor or any reciprocating component to cause leakage.
8	Damage	Liquid traces in suction line may damage the compressor	Liquid traces of refrigerant present in piping at the exit of evaporator constitute no danger

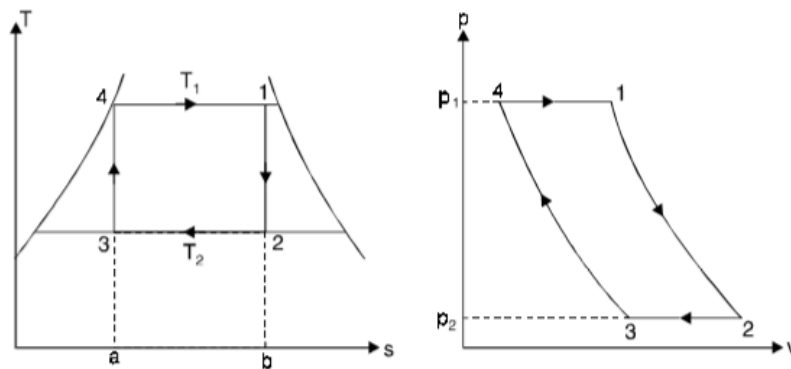


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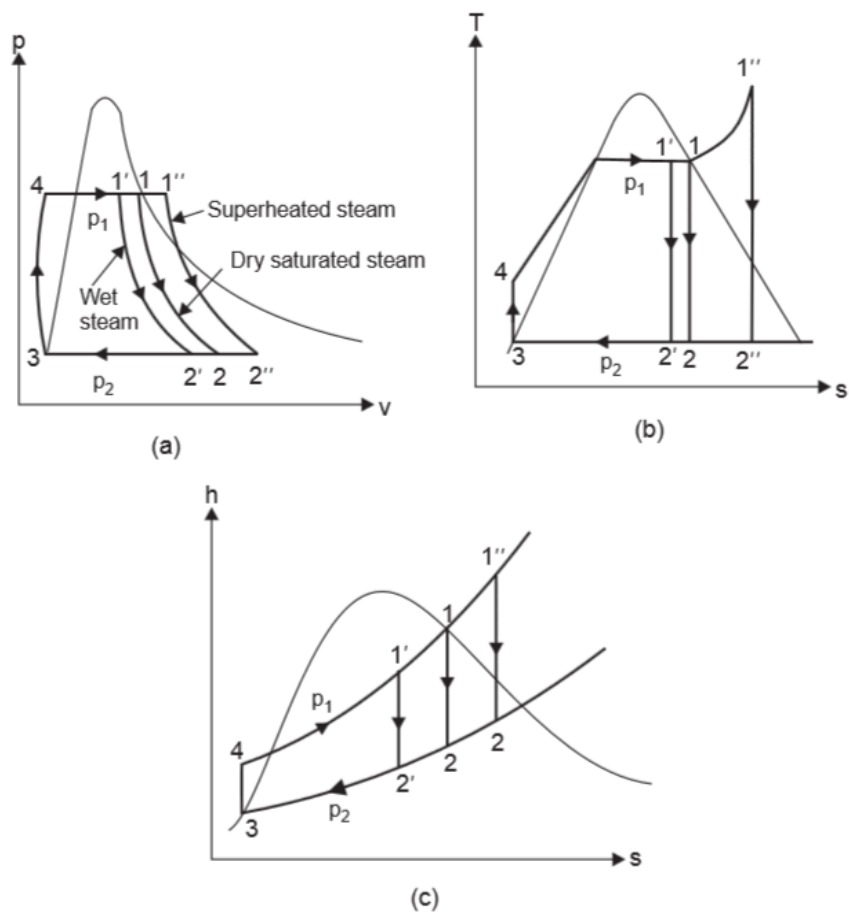
Q.17. Draw p-v and T-s diagram of Carnot cycle.

Ans-



Q. 18. Draw p-v and T-s and h-s diagram of Rankine cycle.

Ans-





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Q.19. What are the Advantages of Regenerative cycle over Simple Rankine cycle ?

Ans-

1. The heating process in the boiler tends to become reversible.
2. The thermal stresses set up in the boiler are minimised. This is due to the fact that temperature ranges in the boiler are reduced.
3. The thermal efficiency is improved because the average temperature of heat addition to the cycle is increased.
4. Heat rate is reduced.
5. The blade height is less due to the reduced amount of steam passed through the low pressure stages.
6. Due to many extractions there is an improvement in the turbine drainage and it reduces erosion due to moisture.
7. A small size condenser is required.

Q.20. what are the advantages of Superheating of steam?

Ans-

The primary object of superheating steam and supplying it to the primemovers is to avoid too much wetness at the end of expansion. Use of inadequate degree of superheat in steam engines would cause greater condensation in the engine cylinder ; while in case of turbines the moisture content of steam would result in undue blade erosion. The maximum wetness in the final condition of steam that may be tolerated without any appreciable harm to the turbine blades is about 12 per cent. Broadly each 1 per cent of moisture in steam reduces the efficiency of that part of the turbine in which wet steam passes by 1 per cent to 1.5 per cent and in engines about 2 per cent.

Q.21. What are the Advantages of 'Reheating' ?

Ans-

1. There is an increased output of the turbine.
2. Erosion and corrosion problems in the steam turbine are eliminated/avoided.
3. There is an improvement in the thermal efficiency of the turbines.
4. Final dryness fraction of steam is improved.
5. There is an increase in the nozzle and blade efficiencies.



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Q.22. What are the applications of air compressors?

Ans-

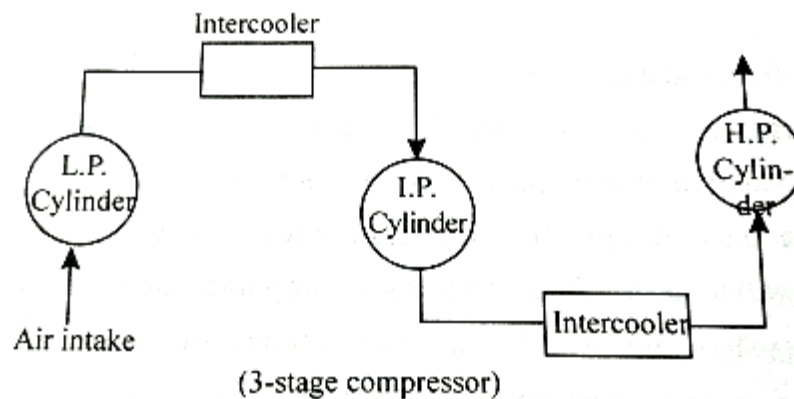
1. It is used to inflate the automobile tyres.
2. It is used to inject fuel in air injection diesel engines.
3. It is used for spray painting.
4. It is used to operate pneumatic circuits.(such as pneumatic drills, hammers, hoist, air brakes,etc)
5. It is used to start IC engine and for supercharging IC engines.
6. It is used for gas turbine plants.
7. It is used for cleaning purposes.
8. It is used in the processing of food and firm maintenance.

Q.23. Define Volumetric Efficiency.

Ans-The volumetric efficiency of a compressor is the ratio of free air delivered to the displacement of the compressor. It is also the ratio of effective swept volume to the swept volume.

Q.24. Why intercooling is done in multistage compressor?

Ans-





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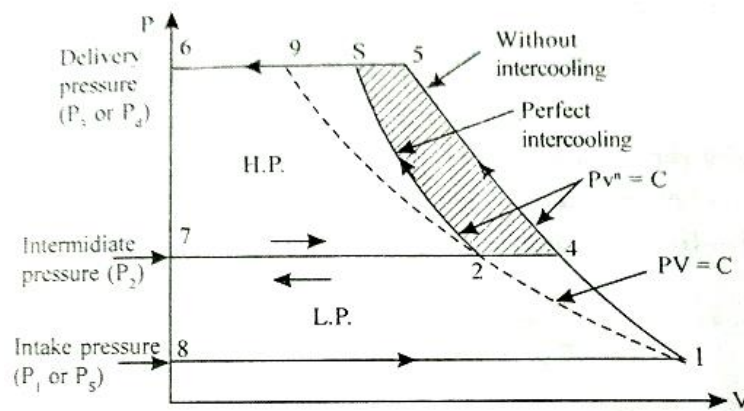


- Multistage compression is a series arrangement of cylinders in which compressed air from the cylinder before, becomes the intake air for the cylinder which follows.
- The effective swept volume of this cylinder increases when pressure ratio is low in low pressure cylinder. Since in this cylinder which controls the mass flow through the machine .
- Because it is this cylinder which introduces the air into the machine, then there is a greater mass flow through the multistage arrangement than the single stage machine.
- In an intercooler the compressed air is cooled between cylinders, then the final delivery temperature is reduced.
- The reduction of temperature means the reduction in internal energy of the delivered air and this energy is used to drive the machine, this results in a decrease in input work requirement for a given mass of delivered air.

Q.25. What is perfect intercooling?

Ans-

Perfect intercooling means that after the initial compression in the L.P. cylinder, with its consequent temperature rise, the air is cooled in an intercooler back to its original temperature.



Q.26. Define available and unavailable energy.

- There are many forms in which an energy can exist. But even under ideal conditions all these forms cannot be converted completely into work. This indicates that energy has two parts :
 - Available part.
 - Unavailable part.



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- 'Available energy' is the maximum portion of energy which could be converted into useful work by ideal processes which reduce the system to a dead state (a state in equilibrium with the earth and its atmosphere). Because there can be only one value for maximum work which the system alone could do while descending to its dead state, it follows immediately that 'Available energy' is a property.
- A system which has a pressure difference from that of surroundings, work can be obtained from an expansion process, and if the system has a different temperature, heat can be transferred to a cycle and work can be obtained. But when the temperature and pressure becomes equal to that of the earth, transfer of energy ceases, and although the system contains internal energy, this energy is unavailable.
- Summarily available energy denote, the latent capability of energy to do work, and in this sense it can be applied to energy in the system or in the surroundings.
- The theoretical maximum amount of work which can be obtained from a system at any state p_1 and T_1 when operating with a reservoir at the constant pressure and temperature p_0 and T_0 is called 'availability'.

Q..27.What is Helmholtz function?

Ans-

The work done in a non-flow reversible system (per unit mass) is given by :

$$W = Q - (u_0 - u_1) = T \cdot ds - (u_0 - u_1)$$

$$= T (s_0 - s_1) - (u_0 - u_1)$$

$$\text{i.e., } W = (u_1 - Ts_1) - (u_0 - Ts_0)$$

The term $(u - Ts)$ is known as Helmholtz function. This gives maximum possible output when the heat Q is transferred at constant temperature and is the case with a very large source.

Q.28. What is Gibb's function?

Ans-

If work against atmosphere is equal to $p_0 (v_0 - v_1)$, then the maximum work available,

$$W_{\max} = W - \text{work against atmosphere}$$

$$= W - p_0 (v_0 - v_1)$$

$$= (u_1 - Ts_1) - (u_0 - Ts_0) - p_0 (v_0 - v_1)$$

$$= (u_1 + p_0 v_1 - Ts_1) - (u_0 + p_0 v_0 - Ts_0)$$

$$= (h_1 - Ts_1) - (h_0 - Ts_0)$$

$$\text{i.e., } W_{\max} = g_1 - g_0$$



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where $g = h - T.s$ is known as Gibb's function or free energy function.

Q.29. Define irreversibility.

Ans-

The actual work which a system does is always less than the idealized reversible work, and the difference between the two is called the irreversibility of the process.

Thus, Irreversibility, $I = W_{\max} - W$

Q. 30. Define effectiveness.

Ans-

Effectiveness is defined as the ratio of actual useful work to the maximum useful work. The useful output of a system is given by the increase of availability of the surroundings.

$$\text{Effectiveness, } \varepsilon = \frac{\text{Increase in availability of surroundings}}{\text{Loss of availability of system}}$$

For a compression or heating process the effectiveness is given by

$$\text{Effectiveness, } \varepsilon = \frac{\text{Increase in availability of system}}{\text{Loss of availability of surroundings}} = \frac{W_{\text{useful}}}{W_{\max, \text{useful}}}$$

The effectiveness of an actual process is always less than unity. Thus effectiveness of a process is the measure of the extent to which advantage has been taken of an opportunity to obtain useful work.

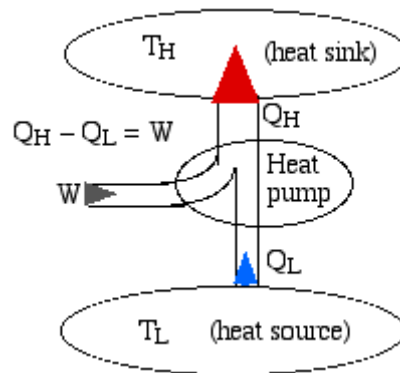
Q.31. Prove that COP of heat pump is greater than COP of refrigerator by unity.

Heat Pumps

- A device that transfers heat from a low-temperature medium to a high-temperature one is the heat pump
- The objective of a heat pump, however, is to maintain a heated space at a high temperature. This is accomplished by absorbing heat from a low-temperature source, such as well water or cold outside air in winter, and supplying this heat to the high-temperature medium such as a house



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Relationship between Coefficient of Performance of a Refrigerator (COP_R) and a Heat Pump (COP_{HP}).

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{W_{net,in} + Q_L}{Q_H - Q_L}$$

$$COP_{HP} = \frac{W_{net,in}}{Q_H - Q_L} + \frac{Q_L}{Q_H - Q_L} = 1 + COP_R$$

$$COP_{HP} = 1 + COP_R$$

Q.32. . what is the difference between isentropic process and adiabatic process? “Isentropic process is reversible, it must be adiabatic”. Explain the sentence.

Ans-

- Adiabatic process is defined as a process in which there is no heat transfer.
- The infinitesimal change in entropy dS due to reversible heat transfer dQ at temperature T is

$$dS = \frac{dQ_{rev}}{T}$$

- If $dQ_{rev}=0$, i.e., the process is reversible and adiabatic

$$dS=0$$

Or

$$S=\text{constant}$$

A reversible adiabatic process is, therefore, an isentropic process.



Q.33. Mention Maxwell's equations.

Ans-

$$\left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial p}{\partial s}\right)_v$$

$$\left(\frac{\partial T}{\partial p}\right)_s = \left(\frac{\partial v}{\partial s}\right)_p$$

$$\left(\frac{\partial p}{\partial T}\right)_v = \left(\frac{\partial s}{\partial v}\right)_T$$

$$\left(\frac{\partial v}{\partial T}\right)_p = -\left(\frac{\partial s}{\partial p}\right)_T$$

These equations are known as Maxwell relations.

Q.34. Mention second law of the thermodynamics (K-P and Clausius statement).

Ans-

- **The Kelvin-Planck statement of the second law states;** it is impossible for a heat engine to produce net work in a complete cycle if it exchanges heat only with bodies at a single fixed temperature.
- **Clausius' statement of the second law** gives; It is impossible to construct a device which, operating in a cycle, will produce no effect other than the transfer of heat from a cooler to a hotter body.

Q.35. Why is Carnot cycle not practicable for a steam power plant?

Ans-

Though Carnot cycle is simple (thermodynamically) and has the highest thermal efficiency for given values of T_1 and T_2 , yet it is extremely difficult to operate in practice because of the following reasons:

1. It is difficult to compress a wet vapour isentropically to the saturated state as required by the process 3-4.
2. It is difficult to control the quality of the condensate coming out of the condenser so that the state '3' is exactly obtained.
3. The efficiency of the Carnot cycle is greatly affected by the temperature T_1 at which heat is transferred to the working fluid. Since the critical temperature for steam is only 374°C , therefore, if the cycle is to be operated in the wet region, the maximum possible temperature is severely limited.



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4. The cycle is still more difficult to operate in practice with superheated steam due to the necessity of supplying the superheat at constant temperature instead of constant pressure (as it is customary). ☐

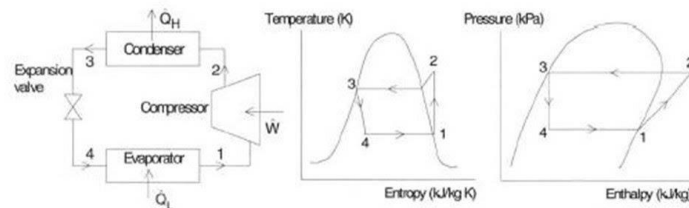
- In a practical cycle, limits of pressure and volume are far more easily realised than limits of temperature so that at present no practical engine operates on the Carnot cycle, although all modern cycles aspire to achieve it.

Q.36. Draw the T-s and h-s diagrams for the vapour compression refrigeration cycle.

Ans-

VCR

Vapour Compression Refrigeration Cycle



$$\text{COP} = \frac{h_1 - h_4}{h_2 - h_1}$$

Q.37. What is the effect of regeneration on the (i) the cycle efficiency (ii) specific output (iii) mean temperature of heat addition of a steam power plant?

Ans-

- It was found that increasing of regeneration effectiveness results in an increase in the output power of the cycle.
- It was also found that the cycle thermal efficiency increases with increasing of the regenerative effectiveness.
- The thermal efficiency is improved because the mean temperature of heat addition to the cycle is increased.



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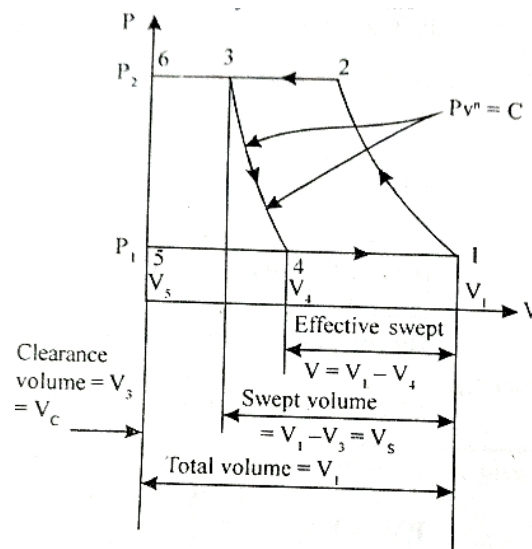
Q.38. What are availability functions for a (i) closed system and (ii) a steady flow system?

Ans-

- The property, $a = u + p_0v - T_0s$ (per unit mass) is called the non-flow availability function for a closed system.
- The property, $b = h - T_0s$ (per unit mass) is called the steady-flow availability function.
- [In the equation $b = h - T_0s$; the function 'b' (like the function 'a') is a composite property of a system and its environment; this is also known as Keenan function].

Q.39. Derive: $\eta_{Vol} = 1 + C - C \left(\frac{P_2}{P_1} \right)^{\frac{1}{n}}$

Ans-



- The volumetric efficiency of a compressor is the ratio of free air delivered to the displacement of the compressor. It is also the ratio of effective swept volume to the swept volume.



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$$\text{Volumetric efficiency} = \frac{\text{Effective swept volume}}{\text{swept volume}} = \frac{V_1 - V_4}{V_1 - V_3}$$

$$\text{The ratio, } \frac{\text{clearance volume}}{\text{swept volume}} = \frac{V_3}{V_1 - V_3} = \frac{V_C}{V_S} = C$$

$$\begin{aligned} \eta_{\text{Vol}} &= \frac{V_1 - V_4}{V_1 - V_3} = \frac{(V_1 - V_3) + (V_3 - V_4)}{(V_1 - V_3)} = 1 + \frac{V_3}{V_1 - V_3} - \frac{V_4}{V_1 - V_3} \\ &= 1 + \frac{V_3}{V_1 - V_3} - \frac{V_4}{V_1 - V_3} \cdot \frac{V_3}{V_3} = 1 + \frac{V_3}{V_1 - V_3} - \frac{V_3}{V_1 - V_3} \cdot \frac{V_4}{V_3} = 1 + C - C \cdot \frac{V_4}{V_3} \\ &= 1 + C - C \left(\frac{P_3}{P_4} \right)^{\frac{1}{n}} \end{aligned}$$

$$P_3 V_3^n = P_4 V_4^n \Rightarrow \frac{V_4}{V_3} = \left(\frac{P_3}{P_4} \right)^{\frac{1}{n}}$$

$$\eta_{\text{Vol}} = 1 + C - C \left(\frac{P_2}{P_1} \right)^{\frac{1}{n}} \left[\because P_3 = P_2, P_4 = P_1 \right]$$

$$\Rightarrow \eta_{\text{Vol}} = 1 + C - C \left(\frac{V_1}{V_2} \right)$$

Q.40. Compare Otto, Diesel and Dual cycle for the Same Compression Ratio and the Same Heat Input.

Ans-

- A comparison of the cycles (Otto, Diesel and Dual) on the p-v and T-s diagrams for the same compression ratio and heat supplied is shown in the Fig.

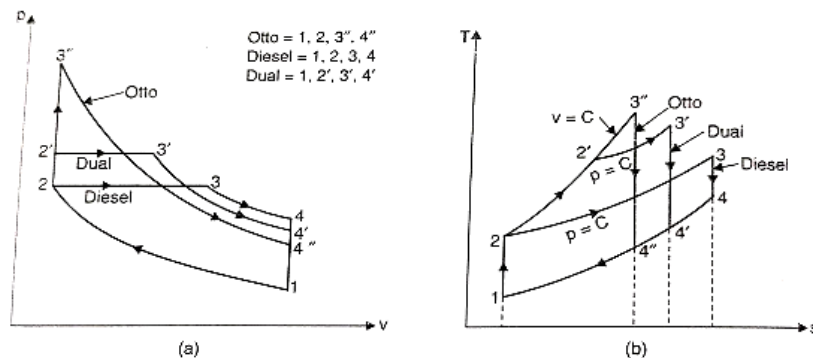


Fig. (a) p - v diagram, (b) T - s diagram.



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- We know that, $\eta = 1 - \frac{\text{heat rejected}}{\text{heat supplied}} \dots\dots\dots(i)$
- Since all the cycles reject their heat at the same specific volume, process line from state 4 to 1, the quantity of heat rejected from each cycle is represented by the appropriate area under the line 4 to 1 on the T-s diagram. As is evident from the eqn. (i) the cycle which has the least heat rejected will have the highest efficiency. Thus, Otto cycle is the most efficient and Diesel cycle is the least efficient of the three cycles. i.e., $\eta_{\text{otto}} > \eta_{\text{dual}} > \eta_{\text{diesel}}$

Q.41. Compare Otto and Diesel cycle for Constant Maximum Pressure and Heat Supplied.

Ans-

- Fig. shows the Otto and Diesel cycles on p-v and T-s diagrams for constant maximum pressure and heat input respectively.

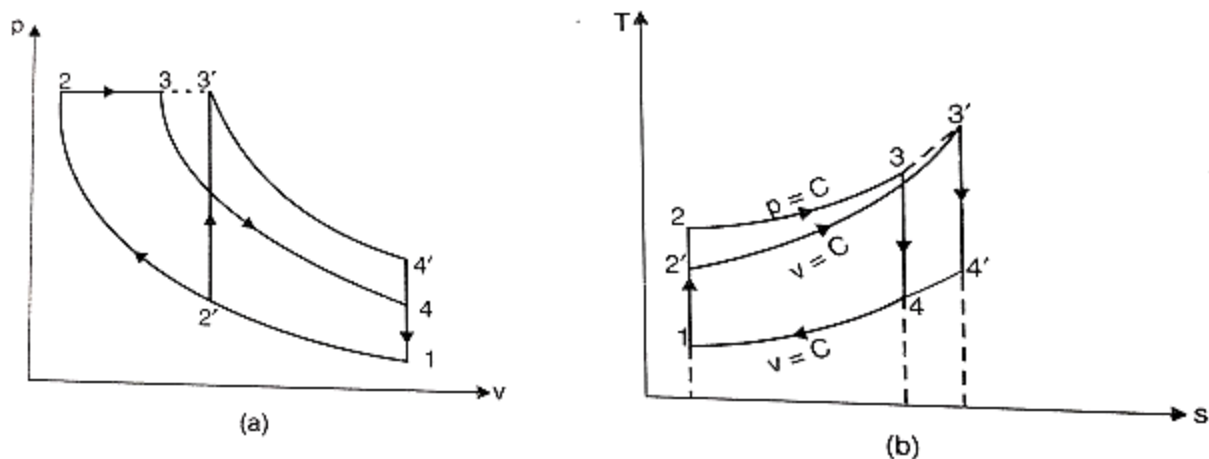


Fig. (a) p-v diagram, (b) T-s diagram.

- For the maximum pressure the points 3 and 3' must lie on a constant pressure line.
- On T-s diagram the heat rejected from the Diesel cycle is represented by the area under the line 4 to 1 and this area is less than the Otto cycle area under the curve 4' to 1 ; hence the Diesel cycle is more efficient than the Otto cycle for the condition of maximum pressure and heat supplied.

Q.42. Explain the effects of intercooling on Brayton cycle performance.

Ans-

A compressor in a gas turbine cycle utilizes the major percentage of power developed by the gas turbine. The work required by the compressor can be reduced by compressing the air in two stages and incorporating an intercooler between the two as shown in Fig.. The corresponding T-s diagram for the unit is shown in Fig.. The actual processes take place as follows :



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1-2' ... L.P. (Low pressure) compression

2'-3 ... Intercooling

3-4' ... H.P. (High pressure) compression

4'-5 ... C.C. (Combustion chamber)-heating

5-6' ... T (Turbine)-expansion

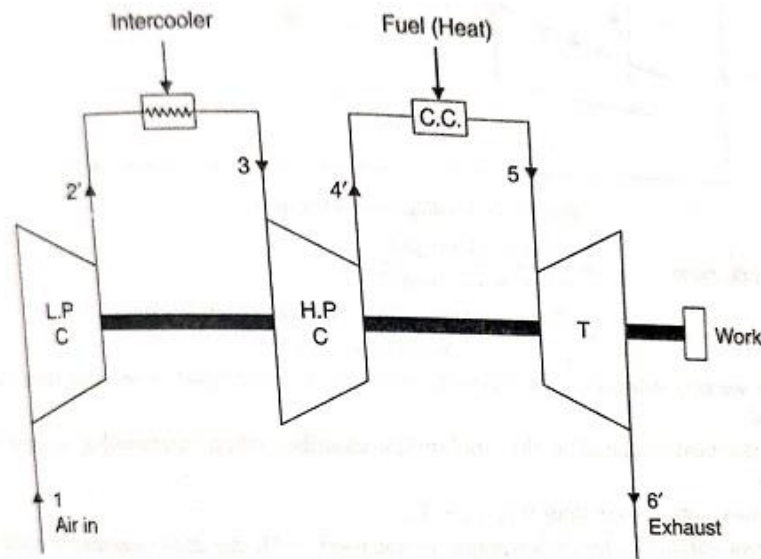


Fig. Turbine plant with intercooler.

The ideal cycle for this arrangement is 1-2-3-4-5-6 ; the compression process without intercooling is shown as 1-L' in the actual case, and 1-L in the ideal isentropic case.

Now, Work input (with intercooling)

$$= c_p(T_{2'} - T_1) + c_p(T_{4'} - T_3)$$

Work input (without intercooling)

$$= c_p(T_{L'} - T_1) = c_p(T_{2'} - T_1) + c_p(T_{L'} - T_{2'})$$

By comparing both equations it can be observed that the work input with intercooling is less than the work input with no intercooling, when $c_p(T_{4'} - T_3)$ is less than $c_p(T_{L'} - T_{2'})$.

This is so if it is assumed that isentropic efficiencies of the two compressors, operating separately, are each equal to the isentropic efficiency of the single compressor which would be required if no intercooling were used. Then $(T_{4'} - T_3) < (T_{L'} - T_{2'})$ since the pressure lines diverge on the T-s diagram from left to the right.

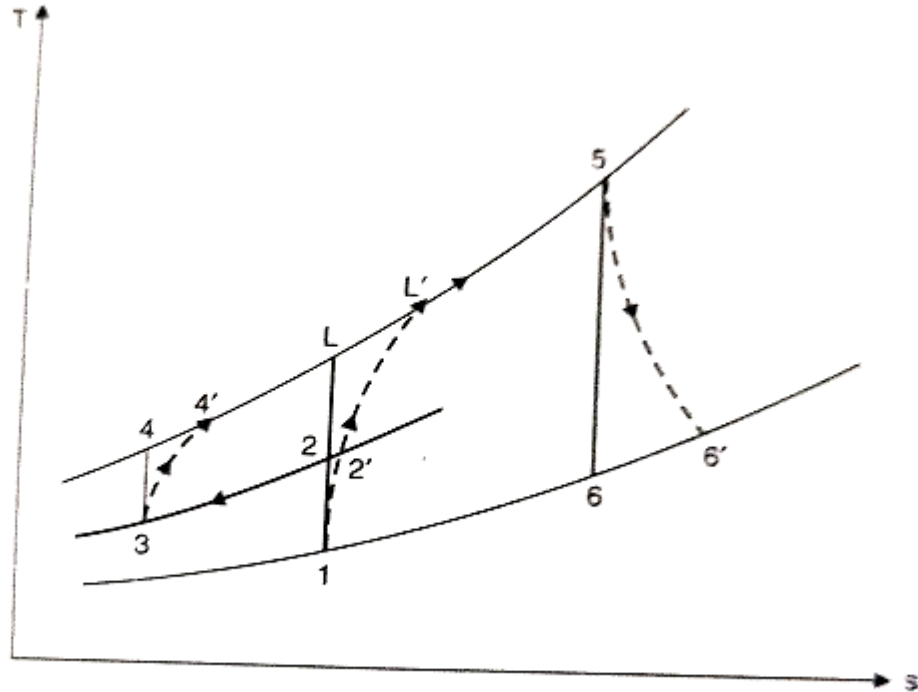


Fig. T - s diagram for the unit.

$$\text{Again, } \text{workratio} = \frac{\text{networkoutput}}{\text{grossworkoutput}} = \frac{\text{workof exp ansion} - \text{workofcompression}}{\text{workof exp ansion}}$$

From this we may conclude that when the compressor work input is reduced then the work ratio is increased.

However the heat supplied in the combustion chamber when intercooling is used in the cycle, is given by,

$$\text{Heat supplied with intercooling} = c_p (T_5 - T_4')$$

Also the heat supplied when intercooling is not used, with the same maximum cycle temperature T_5 , is given by

$$\text{Heat supplied without intercooling} = c_p (T_5 - T_L')$$

Thus, the heat supplied when intercooling is used is greater than with no intercooling. Although the net work output is increased by intercooling it is found in general that the increase in heat to be supplied causes the thermal efficiency to decrease.

When intercooling is used a supply of cooling water must be readily available. The additional bulk of the unit may offset the advantage to be gained by increasing the work ratio.



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Q.43. Explain the effects of reheating on Brayton cycle performance.

Ans-

The output of a gas turbine can be amply improved by expanding the gases in two stages with a reheater between the two as shown in Fig.

The H.P. turbine drives the compressor and the L.P. turbine provides the useful power output. The corresponding T-s diagram is shown in Fig.

The line 4'-L' represents the expansion in the L.P. turbine if reheating is not employed.

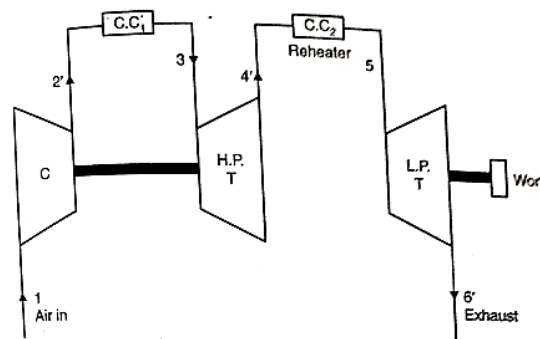


Fig. Gas turbine with reheater.

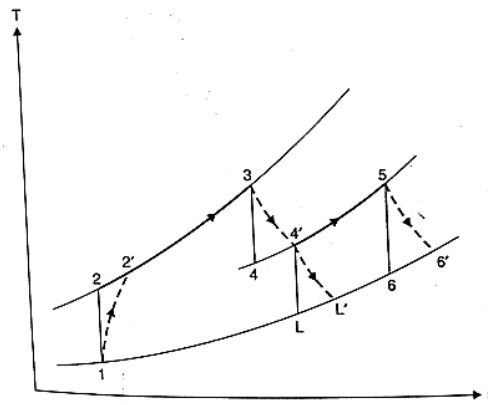


Fig. T-s diagram for the unit.

Neglecting mechanical losses the work output of the H.P. turbine must be exactly equal to the work input required for the compressor i.e., $c_{pa} (T_2' - T_1) = c_{pg} (T_3 - T_4')$

The work output (net output) of L.P. turbine is given by,

$$\text{Net work output (with reheating)} = c_{pg} (T_5 - T_6')$$

$$\text{and Net work output (without reheating)} = c_{pg} (T_4' - T_{L'})$$

Since the pressure lines diverge to the right on T-s diagram it can be seen that the temperature difference $(T_5 - T_6')$ is always greater than $(T_4' - T_{L'})$, so that reheating increases the net work output.



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Although net work is increased by reheating the heat to be supplied is also increased, and the net effect can be to reduce the thermal efficiency

$$\text{Heat supplied} = c_{pg} (T_3 - T_2') + c_{pg} (T_5 - T_4').$$

Note. c_{pa} and c_{pg} stand for specific heats of air and gas respectively at constant pressure.

Q.44. Explain the effects of regeneration Brayton cycle performance.

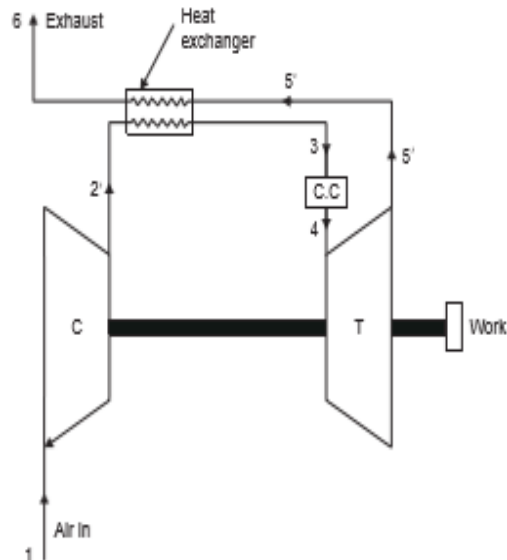
Ans-

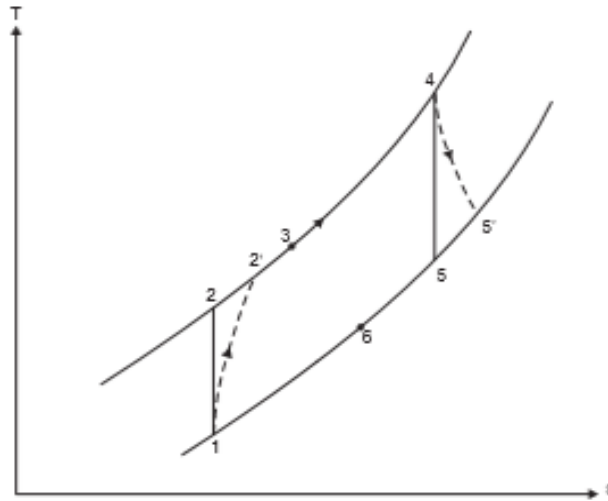
The exhaust gases from a gas turbine carry a large quantity of heat with them since their temperature is far above the ambient temperature. They can be used to heat the air coming from the compressor thereby reducing the mass of fuel supplied in the combustion chamber.

Fig. shows a gas turbine plant with a regenerator. The corresponding T-s diagram is shown in Fig.

2'-3 represents the heat flow into the compressed air during its passage through the heat exchanger and 3-4 represents the heat taken in from the combustion of fuel.

Point 6 represents the temperature of exhaust gases at discharge from the heat exchanger. The maximum temperature to which the air could be heated in the heat exchanger is ideally that of exhaust gases, but less than this is obtained in practice because a temperature gradient must exist for an unassisted transfer of energy.





The effectiveness of the heat exchanger is given by :

$$\text{Effectiveness}(\varepsilon) = \frac{\text{Increase in enthalpy per kg of air}}{\text{Available increase in enthalpy per kg of air}} = \frac{(T_3 - T_2')}{(T_5' - T_2')}$$

(assuming c_{pa} and c_{pg} to be equal)

A heat exchanger is usually used in large gas turbine units for marine propulsion or industrial power.

Q.45. Compare between Rankine Cycle and Carnot Cycle .

Ans-

The following points are worth noting :

- (i) Between the same temperature limits Rankine cycle provides a higher specific work output than a Carnot cycle, consequently Rankine cycle requires a smaller steam flow rate resulting in smaller size plant for a given power output. However, Rankine cycle calls for higher rates of heat transfer in boiler and condenser.
- (ii) Since in Rankine cycle only part of the heat is supplied isothermally at constant higher temperature T_1 , therefore, its efficiency is lower than that of Carnot cycle. The efficiency of the Rankine cycle will approach that of the Carnot cycle more nearly if the superheat temperature rise is reduced.
- (iii) The advantage of using pump to feed liquid to the boiler instead to compressing a wet vapour is obvious that the work for compression is very large compared to the pump.



Q.46. How Rankine cycle efficiency can be improved?

Ans-

- (i) Increasing the average temperature at which heat is supplied.
- (ii) Decreasing/reducing the temperature at which heat is rejected

The thermal efficiency of the Rankine cycle is also improved by the following methods :

- i) By regenerative feed heating.
- (iii) By reheating of steam.
- (iv) By water extraction.
- (v) By using binary-vapour.

Q.47. What is first form of entropy equation or the first Tds equation?

Ans-

- Since entropy may be expressed as a function of any other two properties, e.g. temperature T and specific volume v ,

$$s = f(T, v)$$

$$ds = \left(\frac{\partial s}{\partial T} \right)_v dT + \left(\frac{\partial s}{\partial v} \right)_T dv$$

$$\text{Or, } Tds = T \left(\frac{\partial s}{\partial T} \right)_v dT + T \left(\frac{\partial s}{\partial v} \right)_T dv$$

But for a reversible constant volume change

$$dq = c_v (dT)_v = T (ds)_v \Rightarrow c_v = T \left(\frac{\partial s}{\partial T} \right)_v$$

$$\text{But, } \left(\frac{\partial p}{\partial T} \right)_v = \left(\frac{\partial s}{\partial v} \right)_T$$

So, we get,

$$Tds = c_v dT + T \left(\frac{\partial p}{\partial T} \right)_v dv$$



This is known as the first form of entropy equation or the first Tds equation.

Q.48. what is second form of entropy equation or the second Tds equation?

Ans-

We know, $s = f(T, p)$

$$Tds = T \left(\frac{\partial s}{\partial T} \right)_p dT + T \left(\frac{\partial s}{\partial p} \right)_T dp$$

Where, $c_p = T \left(\frac{\partial s}{\partial T} \right)_p$

Also, $\left(\frac{\partial s}{\partial p} \right)_T = - \left(\frac{\partial v}{\partial T} \right)_p$

Hence,

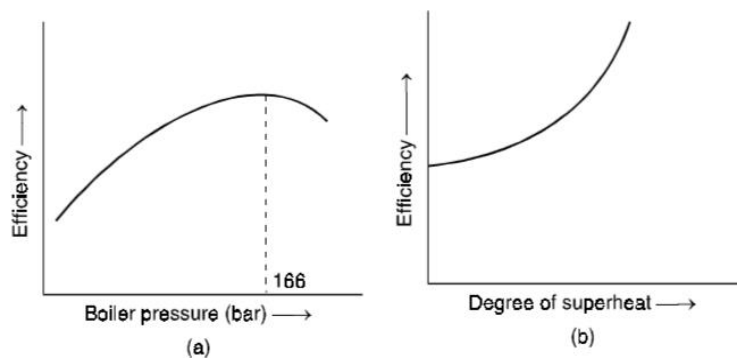
$$Tds = c_p dT - T \left(\frac{\partial v}{\partial T} \right)_p dp$$

This is known as the second form of entropy equation or the second Tds equation.

Q.49. what is the effect of boiler pressure on efficiency of Rankine cycle?

Ans-

It has been observed that by increasing the boiler pressure (other factors remaining the same) the efficiency of the cycle tends to rise and reaches a maximum value at a boiler pressure of about 166 bar [Fig (a)].





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Q.50. what is the effect of condenser pressure on efficiency of Rankine cycle?

Ans-

The thermal efficiency of the cycle can be amply improved by reducing the condenser pressure [Fig (c)] (hence by reducing the temperature at which heat is rejected), especially in high vacuums. But the increase in efficiency is obtained at the increased cost of condensation apparatus.

